Metglas® FINEMET®

HITACHI

Apr.05

Nanocrystalline soft magnetic material

FINEMET®

FINEMET® , this name derives from the combination of “FINE” and “METAL”, which indicates the material’s features of being formed with fine crystal grains and having excellent magnetic properties.
FINEMET® is a registered trademark of Hitachi Metals, Ltd.
***Metglas®* is a registered trademark of Metglas®, Inc.**

This brochure describes characteristics of FINEMET® and gives examples of applications made of FINEMET®

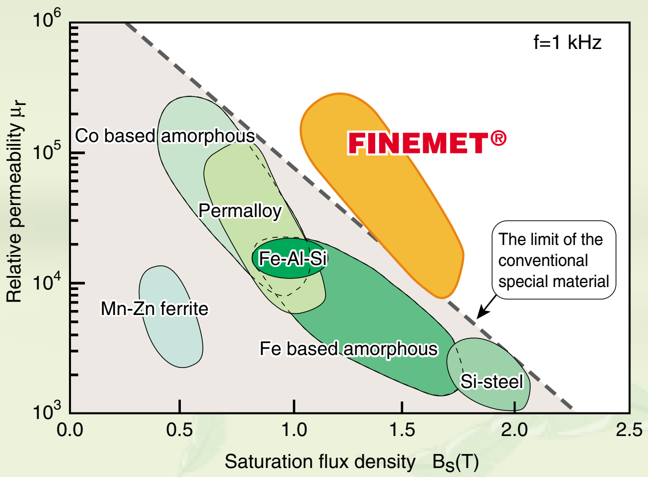
Materials Mag!c
Hitachi Metals

FINEMET® Nanocrystalline Fe-based Soft Magnetic Material with High Saturation Flux Density and Low Core Loss

FINEMET® is the product of Materials Mag!c
The best solution for energy saving, electromagnetic noise reduction and size reduction.

Superior to Conventional Material

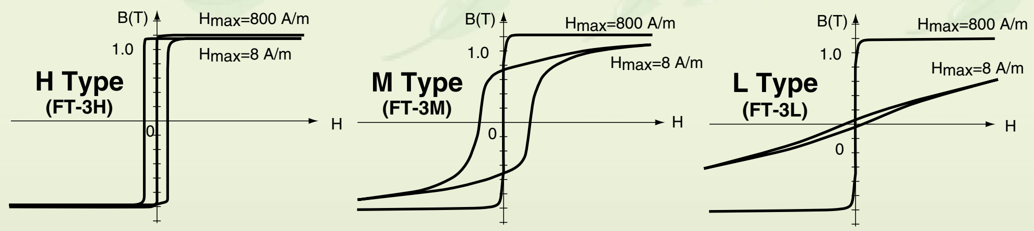
Relationship between relative permeability and saturation flux density of various soft magnetic materials



B-H Curve Control for FINEMET®

FINEMET® core's magnetic properties, "B-H curve" can be controlled by applying a magnetic field during annealing. There are three types of B-H curves. 1) H type: a magnetic field is applied in a circumferential direction during annealing. 2) M type: no magnetic field is applied during annealing. 3) L type: a magnetic field is applied vertically to the core plane during annealing.

Examples of DC B-H curve



H, M or L implies B-H squareness

Features

1) Satisfy both high saturation magnetic flux density and high permeability
High saturation magnetic flux density comparable to Fe-based amorphous metal. High permeability comparable to Co-based amorphous metal.

2) Low core loss
1/5th the core loss of Fe based amorphous metal and approximately the same core loss as Co-based amorphous metal.

3) Low magnetostriction
Less affected by mechanical stress. Very low audio noise emission.

4) Excellent temperature characteristics and small aging effects
Small permeability variation (less than ±10%) at a temperature range of -50℃~150℃. Unlike Co-based amorphous metals, aging effects are very small.

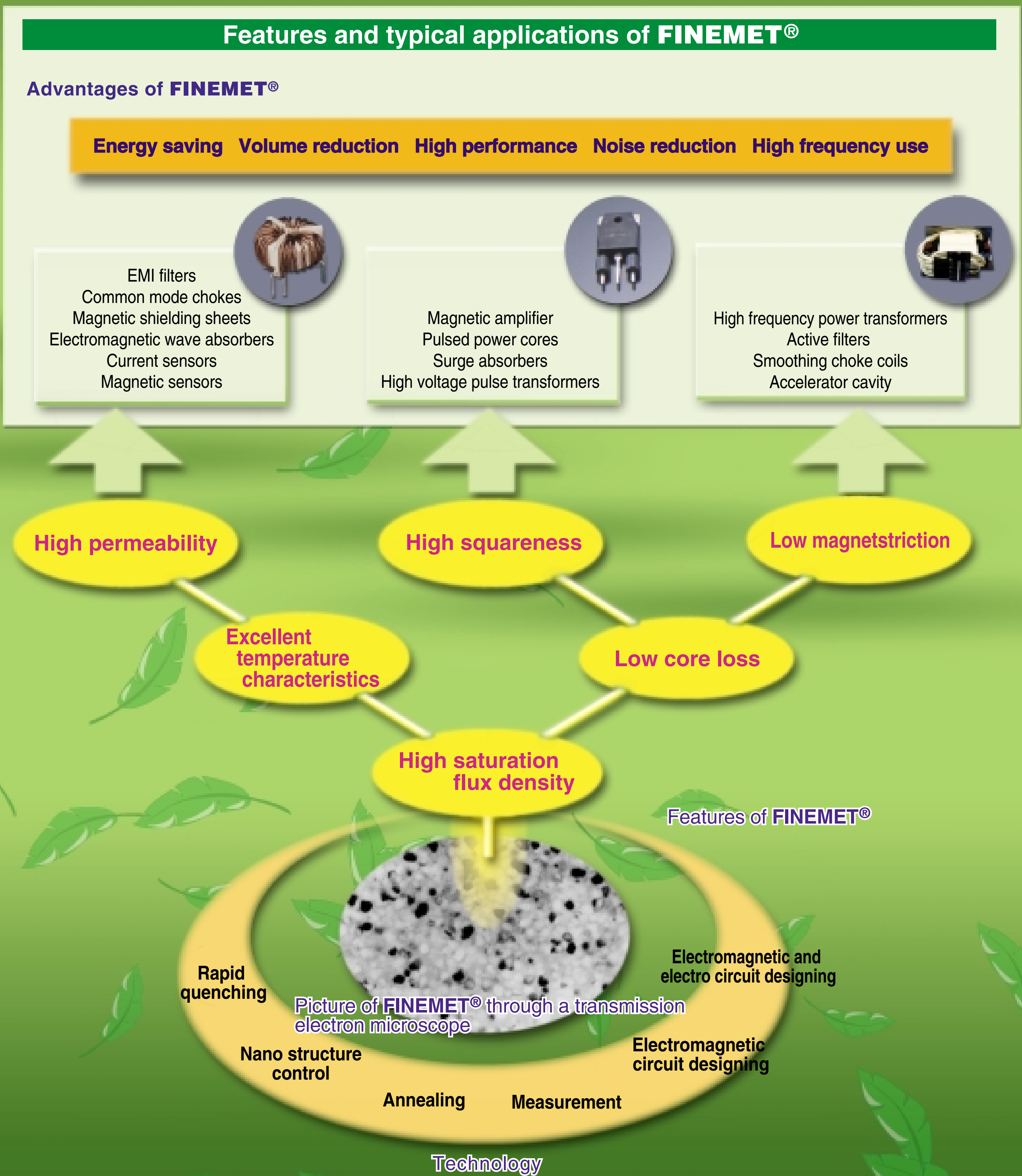
5) Excellent high frequency characteristics
High permeability and low core loss over wide frequency range, which is equivalent to Co-based amorphous metal.

6) Flexibility to control magnetic properties"B-H curve shape"during annealing
Three types of B-H curve squareness, high, middle and low remanence ratio, corresponding to various applications.

What is FINEMET® ?

The precursor of FINEMET® is amorphous ribbon (non-crystalline) obtained by rapid quenching at one million ℃/second from the molten metal consisting of Fe, Si, B and small amounts of Cu and Nb. These crystallized alloys have grains which are extremely uniform and small, "about ten nanometers in size". Amorphous metals which contain certain alloy elements show superior soft magnetic properties through crystallization. It was commonly known that the characteristics of soft magnetic materials are "larger crystal grains yield better soft magnetic properties". Contrary to this common belief, soft magnetic material consisting of a small, "nano-order", crystal grains have excellent soft magnetic properties.

Hitachi Metals Ltd. produces various types of soft magnetic materials, such as Permalloy, soft ferrite, amorphous metal, and FINEMET®, and we use these materials in our product's applications. We continually improve our material technology and develop new applications by taking advantage of the unique characteristics these materials provide. FINEMET® is a good example. It is our hope, FINEMET® will be the best solution for your application.



Major Application of FINEMET®

The followings are examples of FINEMET® application by taking advantage of high permeability, high saturation flux density and low core loss.

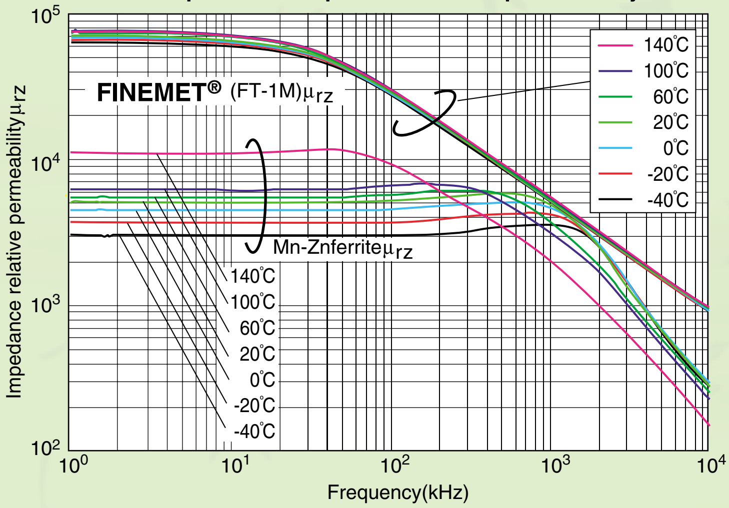
Volume reduction with high permeability

Common Mode Chokes for *EMI filters

FINEMET® has higher impedance permeability (μ_{rz}) and much smaller temperature dependence of permeability over a wider frequency range than Mn-Zn ferrite.
Consequently, the volume of FINEMET® core can be reduced to 1/2 the size of a Mn-Zn ferrite core while maintaining the same performance at operating temperature of 0℃~100℃.
Also, it has approximately three times higher saturation flux density than Mn-Zn ferrite and as a result it is hardly saturated by pulse noise.

*EMI: Electro Magnetic Interference

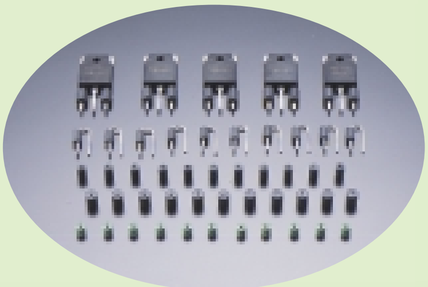
Comparison of impedance relative permeablility



High voltage surge suppression with high saturation flux density

FINEMET® Beads

FINEMET® Beads are made of FINEMET® FT-3M material. As below table describes, the saturation magnetic flux density is twice as high as that of Co-based amorphous metal and Ni-Zn ferrite, and the pulse permeability and the core loss are comparable to Co-based amorphous metal. Because of the high curie temperature (570℃), FINEMET® Beads shows excellent performance at high temperature. These cores are suitable for suppression of reverse recovery current from the diode and ringing or surge current from switching circuit.



Comparison of magnetic and physical properties among FT-3M and conventional materials

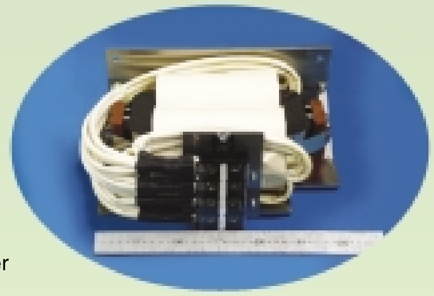
Material		FT-3M	Co-based amorphous	Ni-Zn ferrite
*Saturation flux density B_S (T)	20℃	1.23	0.60	0.38
	100℃	1.20	0.53	0.29
*Squareness ratio B_r/B_S	20℃	0.50	0.80	0.71
	100℃	0.48	0.78	0.60
*Coercive force H_C (A/m)	20℃	2.5	0.30	30
	100℃	2.7	0.29	20
**Pulse permeability μ_{rp}		3,500	4,500	500
**Core loss P_{CV} (J/m^3)		7.5	6.0	7.0
Curie temperature T_C (℃)		570	210	200
Saturation magnetostriction λ_S (X10^{-6})		≃0	≃0	- 7.8
Electrical resisitivity ρ ($\mu\Omega$·m)		1.2	1.3	1X10^{12}
Density d (kg/m^3)		7.3X10^3	7.7X10^3	5.2X10^3

*: DC magnetic properties at 800A/m **: Pulse width 0.1 μs, operating magnetic flux density ΔB=0.2T

Size reduction with low core loss

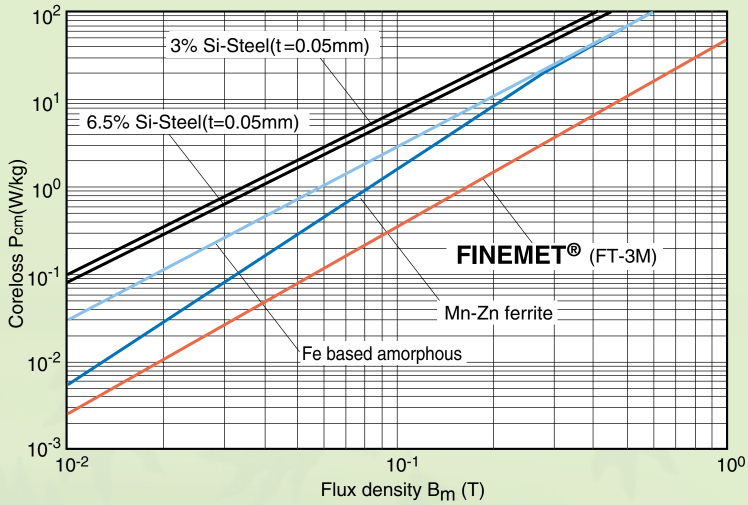
High Frequency Power Transformer

The core loss of FINEMET® (FT-3M) cut core has less than 1/5th the core loss of Fe based amorphous metal and Mn-Zn ferrite, and less than 1/10th the core loss of silicon steel at 10kHz, Bm=0.2T. FINEMET® has significantly lower core loss and thus makes it possible to reduce the size of the core for high frequency power transformer. Also, the magnetostriction of FT-3M is 10^{-7} order and, as a result, cores made from this material will make very little audible noise when compared to cut cores made from Fe based amorphous metal and silicon steel.



10kHz 40kVA
High frequency
power transformer

Comparison of core loss at 10kHz between cut cores



Size reduction and lower core loss

Pulsed Power Cores

FINEMET® pulsed power cores use a thin ceramic insulation which has a high break down voltage. FINEMET® pulsed power cores are suitable for saturable cores and step-up pulse transformer cores that are used in high voltage pulsed power supplies for Excimer lasers and accelerators, and for cavity cores used in induction linacs and RF accelerators.

Comparison of core materials applied in saturable cores for magnetic pulse compression circuit

Core material	FINEMET® FT-3H	Fe-based amorphous metal	Co-based amorphous metal	Ni-Zn ferrite
Insulation	Ceramic	PET film	PET film	–
Effective induction swing $K \cdot \Delta B_m$ (T)	1.54	2.04	0.78	0.65
Half-cycle core loss Pc (J/m^3)	710	1680	180	70
Relative permeability at saturation range $\mu_{r(sat)}$	≃ 1	≃ 1.3	≃ 1	≃ 3
Reset magnetizing force $H_{(reset)}$ (A/m)	8	40	8	160
Volume ratio of saturable cores	1	0.74	3.95	16.8
Total core loss ratio of saturable cores	1	1.75	1.0	1.66

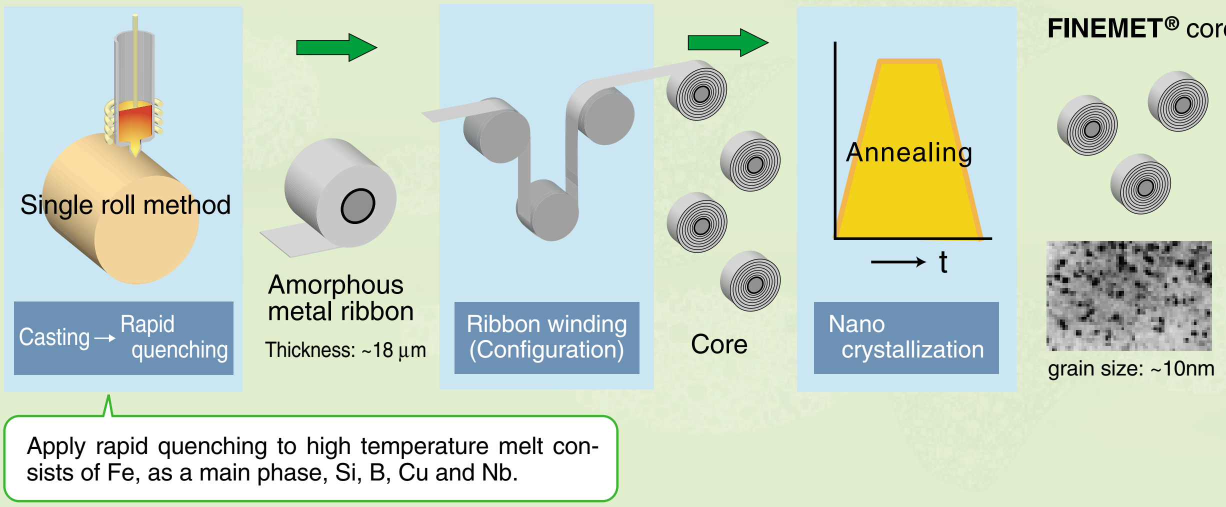
Pulse duration compression ratio: 5.0 (input pulse duration 0.5µs, output pulse duration0.1µs)
K: Packing factor ΔB_m: Maximum operation flux density

Manufacturing Process and Microstructure of **FINEMET®**

Overview of manufacturing process, crystallization process and annealing conditions

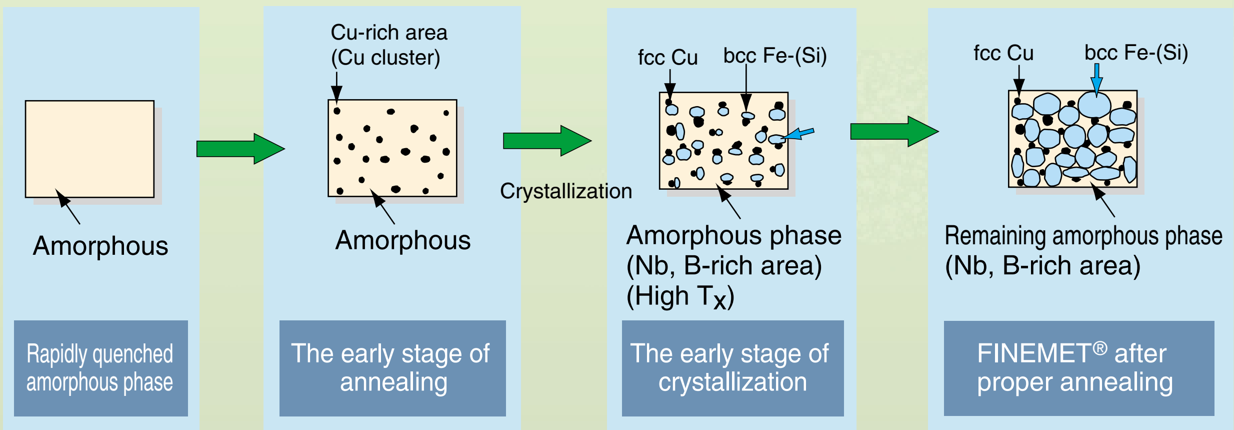
Manufacturing Process of **FINEMET®**

A below diagram shows the process for the creation of amorphous ribbon for FINEMET® and a typical FINEMET® core. The amorphous ribbon is the precursor material of FINEMET®. This ribbon, "which is about 18 µm in thickness", is cast by rapid quenching, called "single roll method", then the amorphous ribbon is wound into a toroidal core. Finally, the heat treatment is applied to the core for crystallization in order to obtain excellent soft magnetic properties of FINEMET®.



Crystallization Process of **FINEMET®**

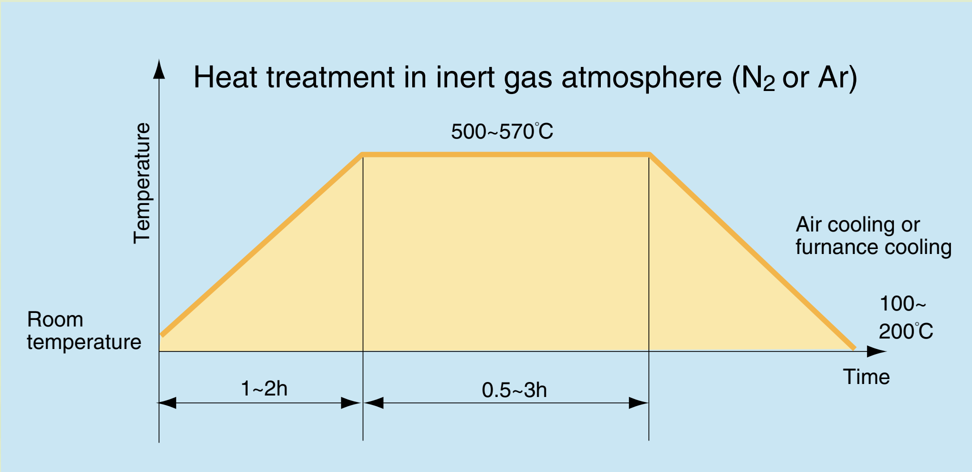
Amorphous metal as a starting point, Amorphous → Cu-rich area → the nucleation of bcc Fe from Cu → bcc Fe(-Si) shows the crystallization process. At the final stage of this crystallization process, the grain growth is suppressed by the stabilized remaining amorphous phase at the grain boundaries. This stabilization occurs because the crystallization temperature of the remaining amorphous phase rises and it becomes more stable through the enrichment of Nb and B. Synergistic effects of Cu addition, "which causes the nucleation of bcc Fe" and Nb addition, "which suppresses the grain growth" creates a uniform and very fine nanocrystalline microstructure.



Annealing Conditions

The diagram shows the typical annealing conditions for M type.
This process requires proper heat treatment conditions according to the desired magnetic properties.

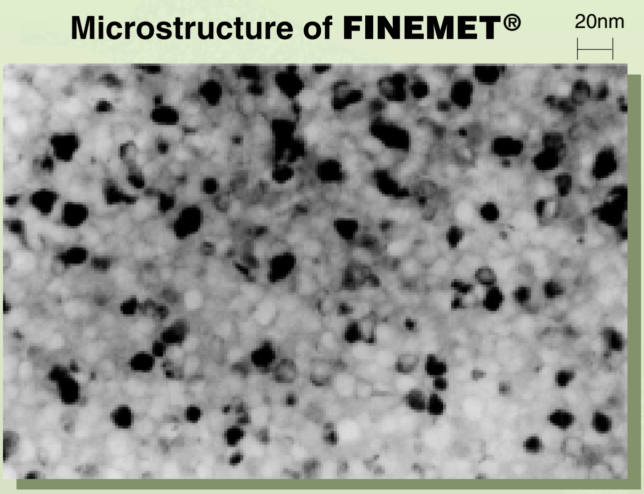
Example of annealing for M type



Microstructure of FINEMET®

A below picture shows the microstructure of FINEMET® through a transmission electron microscope.
FINEMET® consists of ultra fine crystal grains of 10nm order. Main phase is bcc Fe(-Si) and remaining amorphous phase around the crystal grains.

Microstructure of FINEMET®

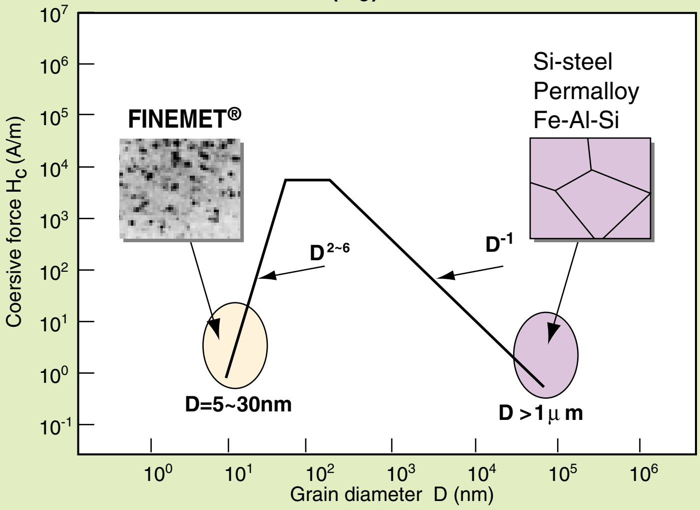


Basic Properties

Grain Size and Coersive Force of Soft Magnetic Materials

In the conventional soft magnetic materials, “whose grain size is far larger than 1µm”, it was well known that soft magnetic properties become worse and coercive force increases when crystal grain size becomes smaller. For example, coercive force is thought to be inversely proportional to D. Therefore, main efforts to improve the soft magnetic properties were directed to make the crystal grain size larger and/or to make the magnetic domain size smaller by annealing and working.
However, FINEMET® demonstrated a new phenomenon; reduction of grain size, “to a nano-meter level”, improves the soft magnetic properties drastically. In this nano-world, the coercive force is directly proportional to D on the order of D^2 to D^6. This is absolutely contrary to the conventional concepts for improving the soft magnetic properties.

Relationship between crystal grain diameter (D) and coercive force (H_C)



Physical Properties

The table shows physical properties of two types of heat-treated FINEMET® materials. FINEMET® has resistivity as high as amorphous metals, and has much lower magnetostriction and about 570℃ higher Curie temperature than Fe-based amorphous metal.
FT-3 is the improved version of FT-1, whose saturation magnetostriction constant of 10^{-7}

Physical properties of FINEMET® materials

Material	Density ($\times 10^3$kg/m³)	Resisitivity (µΩ·m)	Saturation magnetostriction ($\times 10^{-6}$)	Curie temperature (℃)
FT-1	7.4	1.1	+ 2.3	~ 570
FT-3	7.3	1.2	≃ 0	~ 570

*FT-1 and FT-3 describes material property (chemical composition).

Standard Magnetic Characteristics

Magnetic properties of FINEMET® and conventional materials (Non-cut toroidal core)

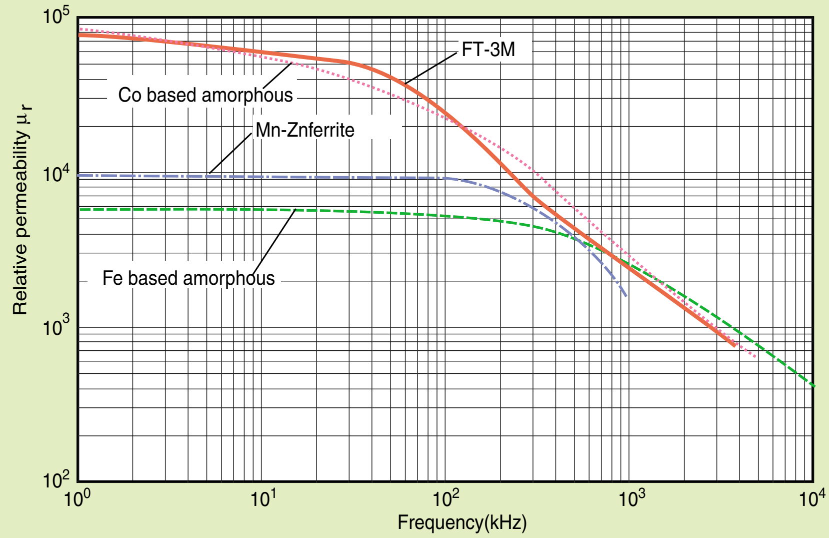
Material		Thickness (µm)	B_S (T)	B_r/B_S (%)	H_C (A/m)	$\mu_{r(1kHz)}$ ($\times 10^3$)	$\mu_{r(100kHz)}$ ($\times 10^3$)	P_{CV} (kW/m³)	λ_S ($\times 10^{-6}$)	T_C (℃)
FINEMET®	FT-1H	18	1.35	90	0.8	5.0	1.5	950	+ 2.3	~ 570
	FT-1M		1.35	60	1.3	70.0	15.0	350		
	FT-3H	18	1.23	89	0.6	30.0	5.0	600	≃ 0	~ 570
	FT-3M		1.23	50	2.5	70.0	15.0	300		
	FT-3L		1.23	5	0.6	50.0	16.0	250		
Fe based amorphous		25	1.56	83	2.4	5.0	5.0	2200	+ 27	415
Co-based high permeability amorphous metal		18	0.55	5	0.3	115.0	18.0	280	≃ 0	180
Co-based high squareness amorphous metal		18	0.60	85	0.3	30.0	10.0	460	≃ 0	210
3%Si-steel		50	1.90	85	6.0	2.7	0.8	8400	- 0.8	750
6.5%Si-steel		50	1.30	63	45.0	1.2	0.8	5800	- 0.1	700
50%Ni Permalloy		25	1.50	95	12.0	–	–	3400	+ 25	500
80% Ni high permeability Permalloy		25	0.74	55	0.5	50.0	5.0	1000	≃ 0	460
80% Ni high squareness Permalloy		25	0.74	80	2.4	–	–	1200	≃ 0	460
Mn-Zn high permeability ferrite		–	0.44	23	8.0	5.3	5.3	1200	- 0.6	>150
Mn-Zn low core loss ferrite		–	0.49	29	12.0	2.4	2.4	680	- 0.6	>200

*Note1: B_s, B_r/B_s, H_c: DC magnetic properties (H_m=800A/m, 25℃), $\mu_{r(1kHz)}$: relative permeability (1kHz, H_m=0.05A/m, 25℃)
$\mu_{r(100kHz)}$: relative permeability (1kHz, H_m=0.05A/m, 25℃), P_{cv}: core loss (100kHz, B_m=0.2T, 25℃), λ_S: Saturation magnetostriction,
T_C: Curie temperature
*Note2: Above properties are taken measurement by Hitachi Metals Ltd.

Frequency Characteristics

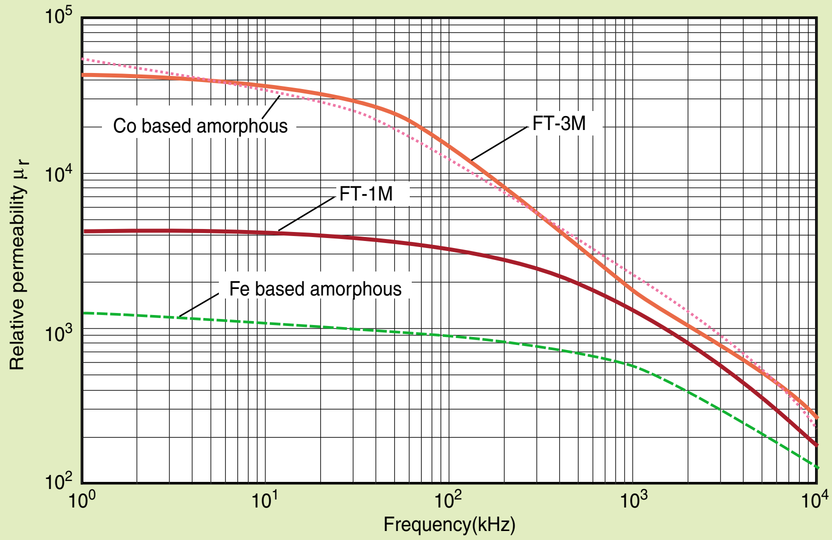
Frequency Dependence of Relative Permeability

The graph shows frequency dependence of relative permeability for FT-3M (medium square ratio of BH curve), Co-based amorphous metal, Fe-based amorphous metal and Mn-Zn ferrite. FT-3M has much higher permeability than Fe based amorphous metals and Mn-Zn ferrite, and has permeability as high as Co-based amorphous metals over a wide frequency range.



Frequency Dependence of Relative Permeability (After resin molding)

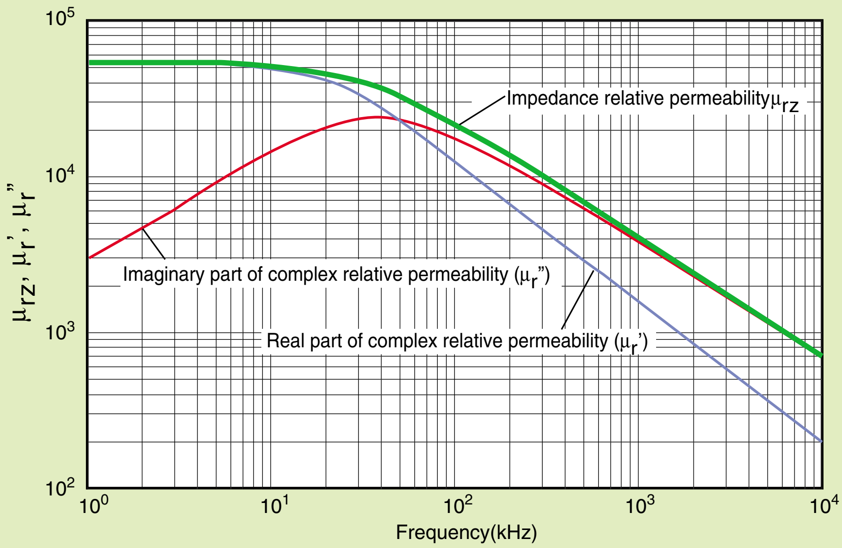
The graph shows frequency dependence of relative permeability for resin molded FT-1M and FT-3M. FT-3M and Co-based amorphous cores show small permeability degradation after the resin molding due to their small magnetostriction.



Complex Relative Permeability and Impedance Relative Permeability

The graph shows real part (μ_r') and imagi-nary part (μ_r'') of the complex relative permeability and the impedance re-lative permeability (μ_{rz}) for FT-1M material. μ_r'' becomes larger than μ_r' 50kHz.
Relationship between μ_{rz}, μ' and μ'' is

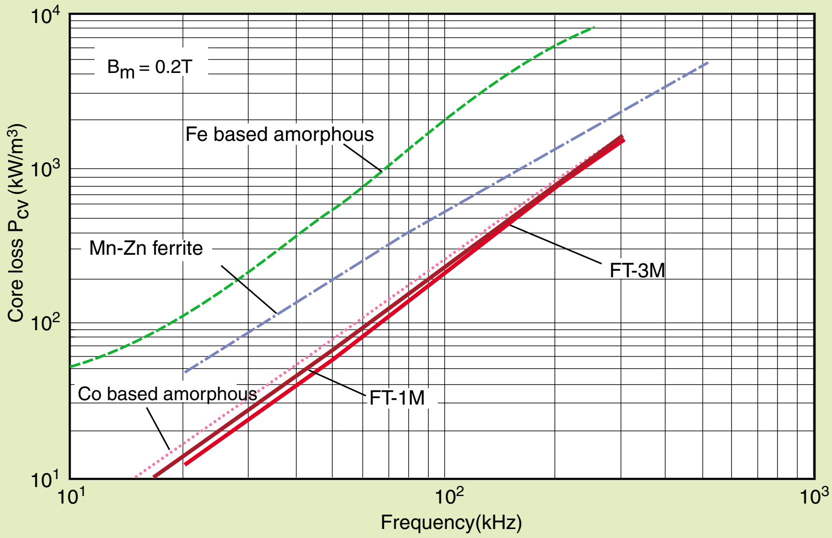
$$\mu_{rz} = \sqrt{\mu_r'^2 + \mu_r''^2}$$



Core Loss

Frequency Dependence of Core Loss (Before resin molding)

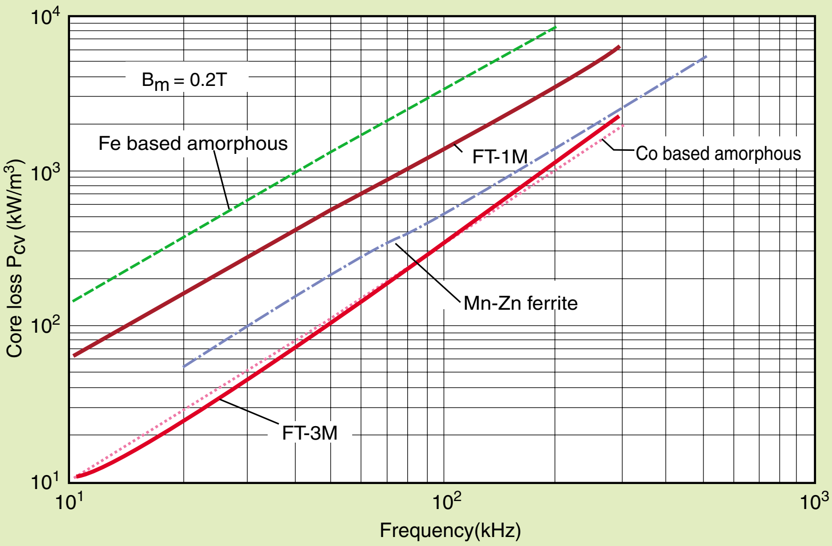
The graph shows frequency dependence of core loss for non-resin molded cores made of FT-1M, FT-3M, Fe-based amorphous metal, Co-based amorphous metal and Mn-Zn ferrite.
FT-1M and FT-3M cores show lower core loss than Mn-Zn ferrite and Fe-based cores, and have the same core loss as Co-based amorphous core.



Frequency Dependence of Core Loss (After resin molding)

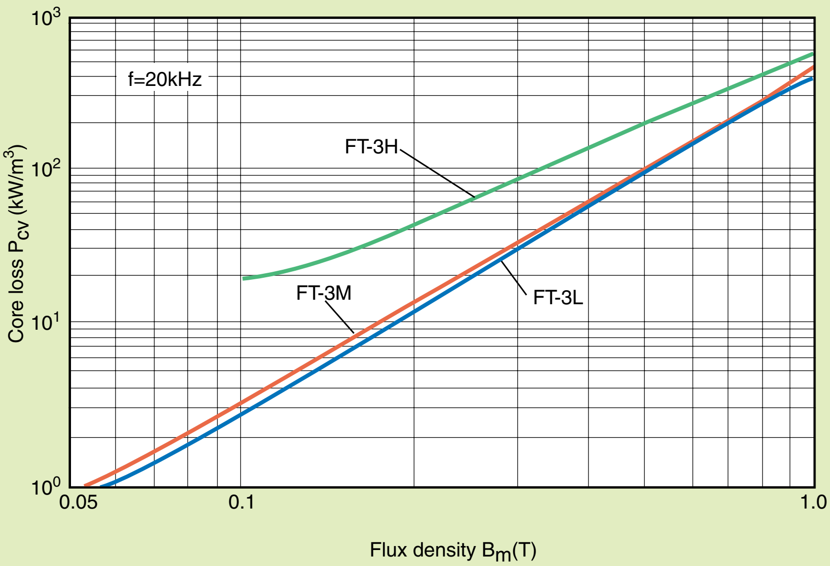
The graph shows frequency dependence of core loss for the resin molded cores made of FT-3M and FT-1M. FT-3M core shows stable core loss over wide frequency range with lower core loss than ferrite cores and have the same core loss as Co- based amorphous core.

*Note: Data may vary depending on resin and/or molding conditions



B_m Dependence of Core Loss

The graph shows B_m dependence of core loss for FT-3H, 3M and 3L at 20kHz. FT-3M and 3L show lower core loss than FT-3H. As B_m becomes higher, core loss difference among those materials becomes smaller.

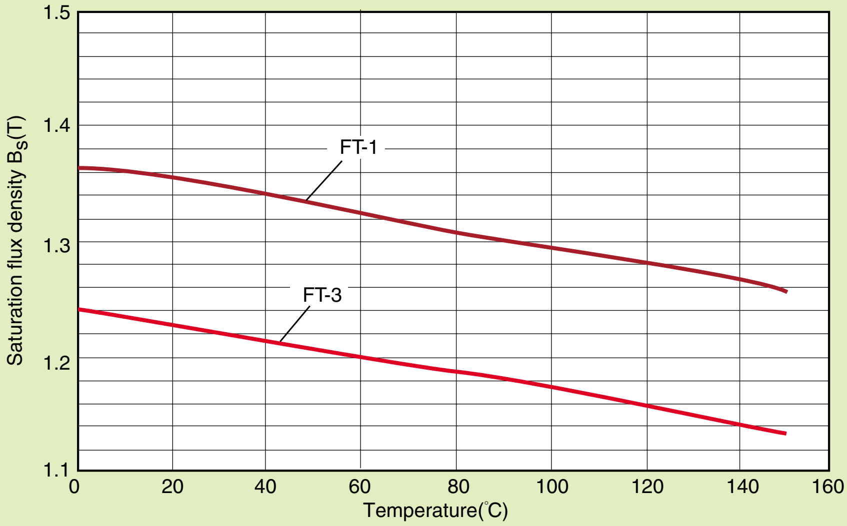


Temperature Characteristics

Temperature Dependence of Saturation Flux Density

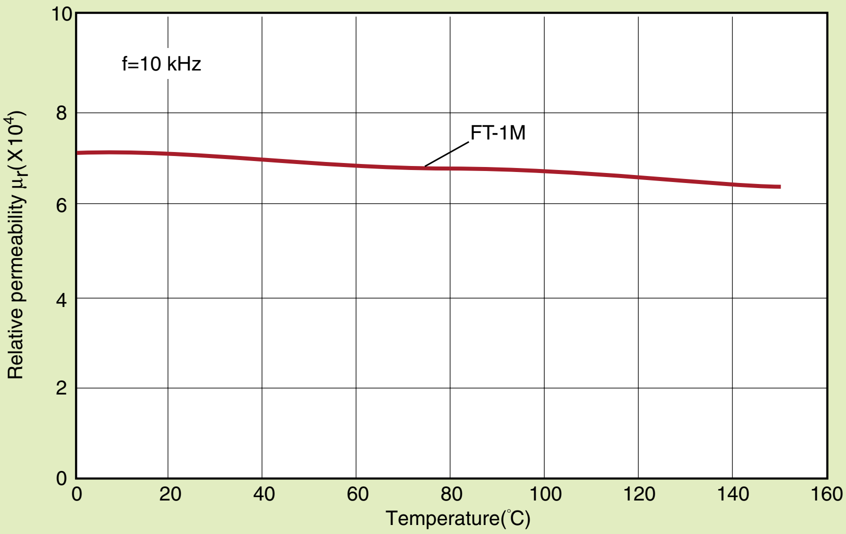
The graph shows temperature dependence of saturation flux density (B_S) for FT-1 and FT-3. Both FT-1 and FT-3 have very small temperature dependence of saturation flux density. The decreasing rate of saturation flux density is less than 10% at range from 25°C to 150°C.

*Note: This data shows value of annealed (crystallized) material.
Because B_S value for H type, M type and L type are same, the data does not describes BH type.



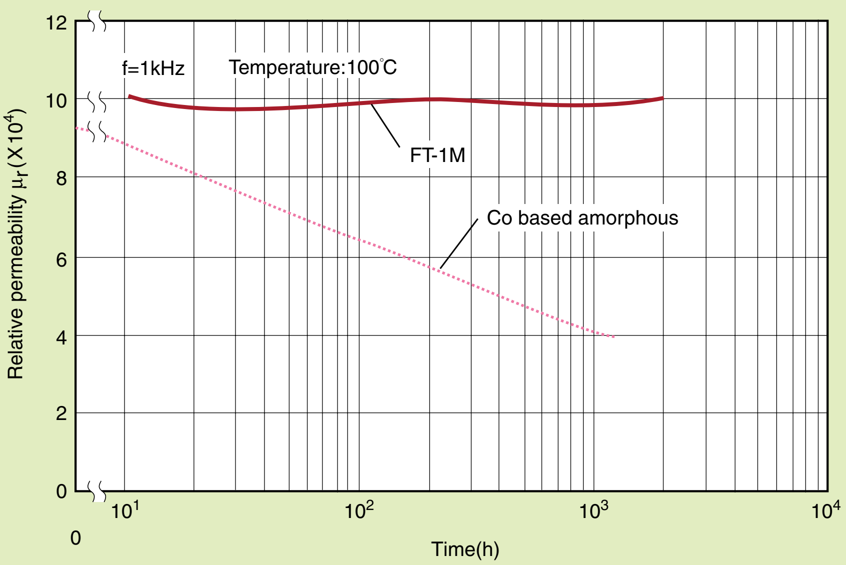
Temperature Dependence of Relative Permeability

The graph shows temperature dependence of relative permeability at 10kHz for FT-1M. The variation of relative permeability is very small at a temperature range from 0°C to 150°C, "which is within ±10% of the average value".



Aging Effect on Relative Permeability

The graph shows aging effects at 100°C on relative permeability at 1kHz for FT-1M and Co-based amorphous metal. The relative permeability of Co-based amorphous metal decrease rapidly as the aging time increasing, however FT-1M is quite stable.



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- Please inquire about our handling manual for specific applications of **FINEMET®**, these manuals detail the exact guaranteed characteristics of **FINEMET®** for a specific application.

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